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Cariboo Forest Region, BC

Soil Temperature on the Long – Term Soil Productivity Study

INTRODUCTION

The Long-Term Soil Productivity (LTSP) Study (Ministry of Forests E.P. 1148) is designed to determine the long-term consequences of organic matter removal and soil compaction. The core LTSP treatments are three levels of organic matter removal crossed with three levels of compaction. The treatments are:

- OM1: merchantable boles only removed
- OM2: om1 plus tops and branches
- OM3: om2 plus forest floor (scalped)
- co: no soil compaction, plots not driven on
- c1: an intermediate severity of compaction
- c2: heavy soil compaction

The LTSP trial is designed to monitor a broad range of possible effects from these treatments. Characteristics being monitored include usual things such as nutrient levels in soil and vegetation, soil physical properties, tree and other vegetative growth and microclimate. More esoteric attributes monitored include populations of soil fauna, fungi and ectomycorrhizae, bacteria, decomposition rates and soil gas composition. The project will ultimately describe the long term effects of soil compaction and organic matter removal as well as the process of recovery of highly disturbed forest soils.

This report discusses results from the three LTSP sites located in three different sub-zones of the Sub-Boreal Spruce biogeoclimatic zone of central BC. Several other replicates of this trial have been and are being installed in other biogeoclimatic zones in the province. The three installations discussed here were the first in BC. Each of these installations has had microclimate monitoring for the first five years of the trial. Soil temperature and moisture and weather data including air temperature at 30 cm, rainfall, standard air temperature and others, are collected at each installation. This note only deals with soil temperature.

The topics which this note covers are:

- How do various levels of organic matter removal affect soil temperatures?

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- How do various levels of compaction affect soil temperatures?
- What are the likely implications of any changes observed?

SITE DESCRIPTIONS

The installation called Log Lake is near Prince George and is located in the SBSwk1 biogeoclimatic subzone and variant. The installation called Topley is in the SBSmc1 and is located near Smithers. The site called Skulow Lake is in the SBSdw2 and is located near Williams Lake. The wk1 site is in the wettest area and the dw2 site is in the driest, considerably drier than the other two sites. At the time of harvest, the Skulow Lake site was a nearly pure lodgepole pine stand. The Log Lake site had quite a mixed stand with sub-alpine fir, Douglas-fir and hybrid spruce. The Topley site was also predominantly lodgepole pine, but also with sub-alpine fir and hybrid spruce. Soil texture at each site was medium and coarse fragment content ranged from 30-40%. More details of the site description can found in LTSP note #4.

METHODS

Temperature probes and data loggers were installed by Dr. Bob Sagar, a consultant in the Prince George area. It was not possible to monitor each treatment so plots for monitoring were chosen to bracket the compaction treatments. Therefore each site has data for all three of the organic matter treatments crossed with no compaction and heavy compaction. Soil temperature is monitored at three depths, 2, 10 and 30 cm. The 2 and 10 cm depths were monitored with three probes each and the 30 cm depth had 2 probes. Data loggers were run year round and daily maximum, minimum and average temperatures were recorded for each probe. Data presented here are from 1996 and 1997.

RESULTS

Effects of Compaction

Winter:

In the winter the effects of soil compaction are easily seen because snow cover dampens diurnal and weather related temperature fluctuations. The different depths and compaction levels tend to acquire slightly different temperatures that remain in the same rank in relation to each other through the winter period. Temperatures usually remain close to zero and very constant, as long as there is snow cover. For example, the average difference between the daily maximum and daily minimum for the wk1 non-compacted 2 cm depth with forest floor intact (om1 and om2) is only 0.20°C. Much of what little variability there is in the winter soil temperatures results from the days, typically in early or late winter, when there is little snow cover. For the shallow depths, the daily fluctuation in temperature are usually slightly greater for the compacted soil. For example, for the compacted treatment the same as above, the average difference between the maximum and minimum daily temperature was 0.28°C.

The compact soils are almost always colder than the non-compacted soil at the same depth. For example, the average maximum temperature over the winter periods at the 30 cm depth is lower in the compacted soils than the non-compacted soil in 8 out of 9 cases for virtually the duration of the winter. In many cases, the deeper compact soil is actually colder than non-compacted soils at a shallower depth. For example, in three cases for the 30 cm depth, the compacted soils are colder than the non-compacted soils at the 10 cm depth on similar treatments. The one case where the compacted soil temperatures were not, on average, colder was for the om3 plots at Skulow Lake (dw sites). In the second winter of data collection, this site had many temperature fluctuations which indicate lack of snow cover, however, the warmer compacted soils are found in both winters. The om3 compacted plot at Skulow Lake is located in a small depression with soils that are significantly wetter than those in the non-compacted plot.

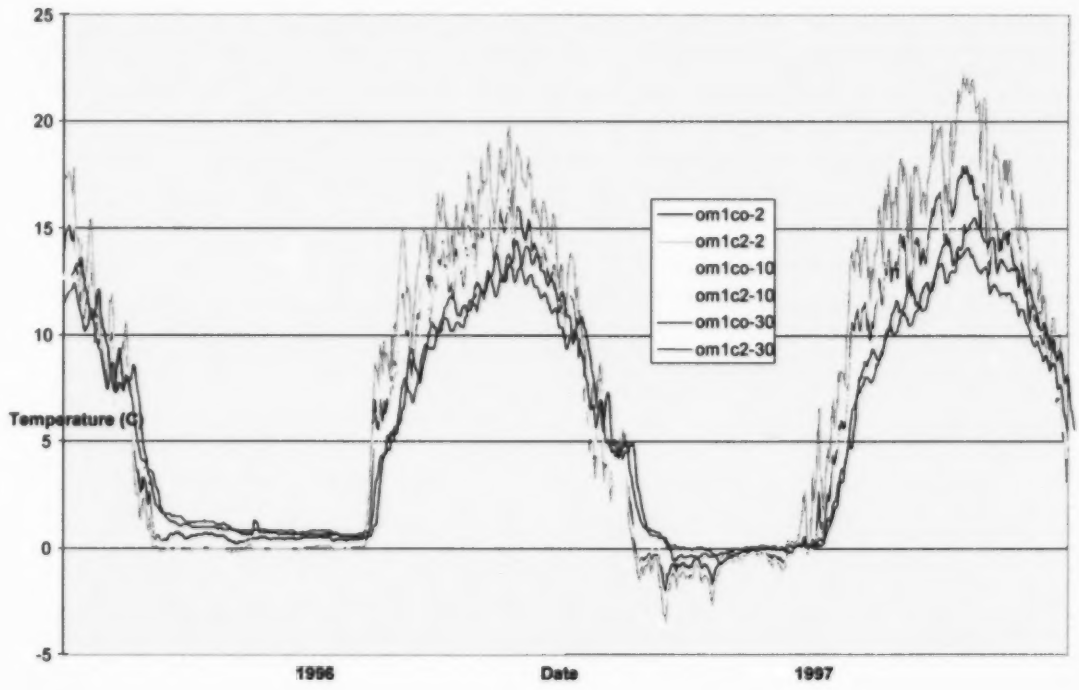
Summer:

Patterns of temperature change in the summer are more difficult to discern because there are

frequent warming and cooling cycles, sub-diurnally, diurnally and in relation to weather. Depending on the direction of temperature change, the ranking of the temperatures of the different treatments changes. During periods of extended warming in the absence of snow cover, there appears to be a tendency for the more compact soils to be "warmer, more often" than the less compact soils, but it is not a foregone conclusion that compact soils are on average warmer. After a period of warming ends, the temperatures of the different treatments begin to drop at different rates, with compact soils cooling more quickly. Temperatures converge and then cross and if given sufficient time, more compact soils cool to lower temperatures than less compact soils. Compact soils are also "colder, more often" than less compact soils. If there has not been an extended period of warming or cooling to widely separate the temperatures of different treatments, then more compact soils can be both warmer and colder than less compact soils over the course of a single day.

After periods of prolonged warming and especially when there is a forest floor layer present, the temperatures of compact and non-compact soils can diverge so much that their temperatures will no longer cross during daily temperature cycles and the compacted soils will become so much warmer that they do not cool down below the temperature of the non-compacted soil in only one day. In some cases, all three depths (2, 10 and 30 cm) of compacted soil are warmer than the shallowest depth of non-compacted soil (2 cm). The summer of 96 at the dw2om1 plots is a good example of this kind of pattern. For the period from April 22 to Sept 15, all compact depths had average maximum temperatures higher than for the non-compacted depths with the compact 2cm depth having the highest average maximum temperature, followed by the compact 10 cm depth (Fig 1).
The average temperatures were slightly different, with all compacted depths still warmer than corresponding non-compacted depths, however for

Figure 1 dw2om1 Average Maximums- All



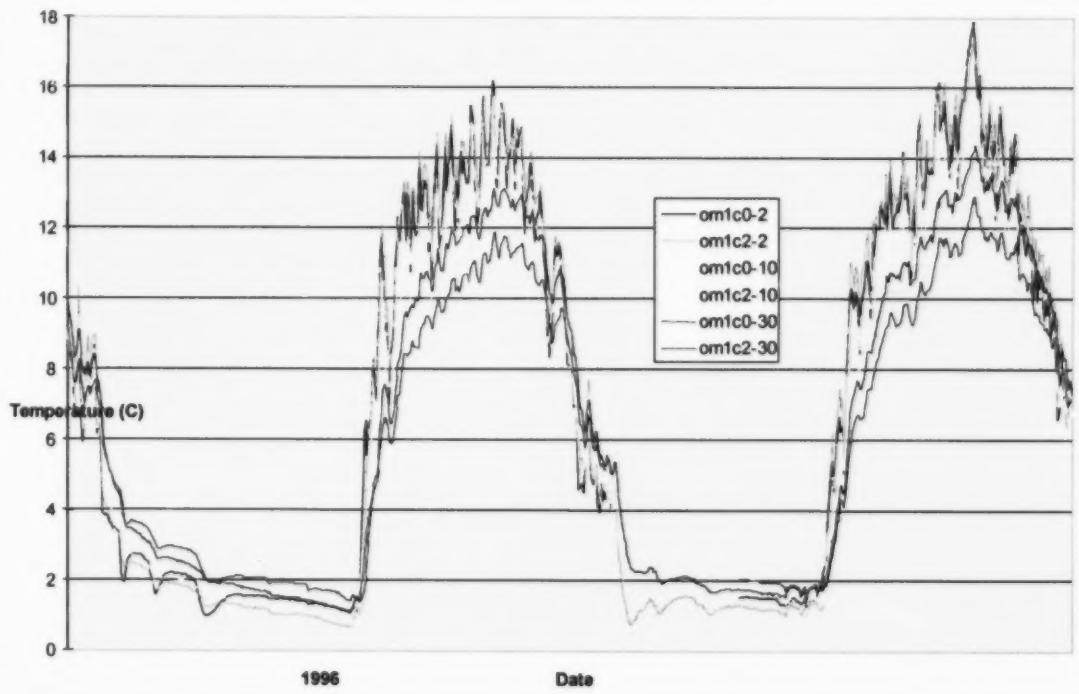
average temperatures, the 2cm depths, compacted and non-compacted, were both warmer than the 10 cm depths. This difference in the ranking between average and maximum temperatures can be explained by the wider temperature fluctuations found in compact soil- even though daily maximums are higher in compacted soil, minimums are frequently lower, which lowers the average daily temperature of the compacted soil.

When a summer is characterized by frequent warming and cooling periods (warming and cooling relative to soil temperature) and/or when there is little or no forest floor to moderate temperature changes, then temperatures fluctuate widely both diurnally and with weather systems. Temperatures for different treatments frequently cross and mean temperatures for the summer period may not be much different between treatments. The wk1om1 plots are a good example of this kind of situation. (Fig 2)

Also, typically in August, soil temperatures begin to drop in relation to the seasonal change and then, usually in October for the three sites in this study, the temperatures cross over for the winter, i.e. what were the warmest soils in summer become the coldest soils and they remain that way until spring. The cooling off period is usually gradual, occurring over about 3 months and short lived warming periods may interrupt the overall cooling trend. Soil temperatures reach winter levels of around 0°C by about November.

In the spring, usually around April, temperatures very suddenly begin to rise and within a day or two, cross over and stay in the same rank, usually, for around a week. During this time, the soil temperatures rise constantly and rapidly. It appears that in the spring, melting snow often keeps soil temperatures suppressed below the temperature of the atmosphere, probably because of heat absorbed by the melting snow. However, once the snow is gone, soil temperature goes through a period of constant warming to catch up with air temperatures. During this period of warming, lasting around one

Figure 2: wk1om1 Average Maximums-



week, all treatments warm very quickly, the temperatures cross over and compact soils warm to higher temperatures. In cases where there is little snow on the ground towards the end of winter, the temperature rise of the soil is more gradual, with warming and cooling spikes and frequent crossing over, back and forth of the temperatures of the different treatments.

Effects of Organic Matter Removal

Winter:

For the 2cm depth, scalping the soil causes a wider (though still small) fluctuation in daily temperature than is found with bole only or boles plus tops and branches harvesting (Table 1). At the 10cm depth, the effect of organic matter removal on temperature fluctuations is reduced and by 30cm depth, there is no difference in the daily temperature fluctuations between the scalped and unscalped treatments (Table 1).

Scalping has a clear, though relatively small, effect on average winter soil temperatures. The om3 (scalped) treatment is the coldest treatment for any given depth and compaction treatment. The om3 treatments in all scenarios, but one, had the lowest daily maximum, minimum and average temperatures. The results for the wk1 non-compacted treatment at 2cm depth are typical of the magnitude of the differences in soil temperature between organic matter removal treatments. The om3 plot average daily maximum temperature for the winter was 1.16°C lower than the average daily maximum temperature of the om2 treatment (stems and branches removed) and the om2 was 0.14°C colder than the om1 treatment (boles only removed).

While the om3 treatment was usually the coldest treatment, the om1 and om2 varied in their ranking depending on the site and treatment. For example, at the non-compacted wk plot, the om2 was colder than the om1 while at the non-compacted mc plot, the om1 was colder than the om2. On the compacted plots, the ranking of the mc2 plots was reversed, with the om2 treatment colder than the om1 but the ranking of the wk sites did not change. A different pattern occurred at the dw site. On the non-compacted dw plots the organic matter treatments were ranked, from coldest to warmest, as om3, om1 and om2. With compaction the ranking changed to om1, om3 and om2. This is an unusual change given the strong tendency for om3 to be the coldest treatment. For the second winter for which data was collected, the dw site appeared to be lacking in snow cover because there were frequent and large temperature fluctuations. However, and as discussed above in the compaction results, the dw-om3 plots had anomalous temperature rankings in both winters and the relationship between compaction and temperature on the dw-om3 plots was reversed from that of other plots. If we assume that the anomaly is with the compact om3 plot, then this accounts for the unusual observations in relation to both organic matter removal and compaction effects.

Summer:

The summer patterns are quite regular for maximum temperatures in relation to level of organic matter removal. The om3 plots are, almost without exception, the warmest, followed by, om2 and then om1. The temperature differences between treatments are large in comparison to those in the winter. Temperature differences between levels of organic matter removal are greatest at the shallowest depths. For example, at the 10 centimetre depth of the mc plots, the om3 plot has an average maximum temperature of 13°C, while the om2 has an average maximum temperature of 8.72°C (difference of 4.28°C). At the 2cm depth, the om3 average maximum is 17.3°C and for the om2 is 9.38 (difference of 7.92° C). The average maximum temperatures of the om1 and om2 treatments are quite constant with depth, for example, the mc2om1 non-compacted soil is only 1.5°C colder at 30cm than at 2cm. The temperature differences with soil depth are much greater for the om3 treatment, approximately 7°C colder at 30cm than at 2cm for the same site. Compacting changes, in a

Table 1: Average difference between daily maximums and minimums by treatment and depth

Treatment-depth	c0-2	c2-2	c0-10	c2-10	c0-30	c2-30
om1 and om2	0.20	0.28	0.17	0.21	0.15	0.18
om3	0.42	0.44	0.25	0.29	0.15	0.18

minor way, the ranking of the average maximum temperatures for some treatments.

The average minimum temperatures are uniquely affected by organic matter removal. The om3 treatments have colder minimum temperatures than other organic matter removal treatments at the shallow depths, but are warmer than other treatments at the deepest depth. Instead of having relatively constant minimum temperature across depths, as is the case with other organic matter removal treatments (e.g., the difference between wk1om1 c0-30cm and c0-2cm is only 0.03°C), the scalped plots become approximately 4°C warmer from the 2cm to 30cm depth for non-compacted soil.. So, the shallow soils on the om3 treatment have the highest maximum temperatures and the lowest minimum temperatures, while at 30 cm, the maximum and minimum temperatures for the om3 treatment are both the highest of all treatments. The temperatures for the 10cm depth fall somewhere in between..

Compacting the soil, on the average, raises the minimum soil temperatures and compresses the extremes so that there is not as much difference between temperatures for the different treatments at a given depth, or between depths for a given treatment. For example, for the compacted om3 treatment the minimum temperature only increases an average of 2.9°C from the 2cm to 30cm depth (versus 3.9°C for non-compacted).

Average soil temperatures are raised by increasing levels of organic matter removal so that whether the soil was compacted or not, for a given site, the om3 treatments had the highest average temperatures, om2 were intermediate and the om1 were the coldest. Overall, there is a slight decline in average temperature with depth, but the rate of decline is quite constant for all treatments at all sites, ranging from about 0.4°C to 1.0 °C, with an average change of 0.66°C.

IMPLICATIONS

The temperature effects of soil compaction and organic matter removal are similar. This is not surprising since both types of treatments alter soil thermal properties in the same way. Compaction increases heat capacity and thermal conductivity while scalping the floor removes a layer of very low thermal conductivity and low heat capacity which in effect is the same as increasing heat capacity and thermal conductivity. The effects of organic matter removal are much greater than those of compaction, which is logical given that forest floor has much lower thermal conductivity and heat capacity than mineral soil, compacted or not.

Treatment effects seem to be much less consequential in the winter when there is snow. The thermal conductivity of snow is so low, and its heat capacity is so high (in particular because of heat absorption as the snow melts) that the differences caused by the treatments are all but masked by the addition of a snow layer. Spring warming patterns are also largely unaffected by treatment because of the suppression of warming in the spring by melting snow, and the surge in warming across all treatments that begins when the last snow melts.

Compacting or scalping a soil results in warmer soils during prolonged periods of warming and colder soils during prolonged periods of cooling. Both treatments result in soils that are, on average, warmer in the summer and colder in the winter. The temperature effects in the summer are many times larger than the effects in the winter. The biological implications of the changes are much more complex than can be indicated by average temperatures, because a complex pattern of changes results from these simple treatments.

Removal of organic matter and compaction both cause wider daily and weather related fluctuations in temperatures,. Very little is know about the biological effects of temperature fluctuation but it is known that most, if not all, plants have an optimum temperature range for root growth. A general rule is that optimum growth occurs around 18- 21°C. Root growth generally stops above about 30° C and below 4°C. Scalping commonly results in 2cm depth maximum temperatures of greater than 30°C for months at a time and greater than 40°C for periods of more than a week at a time, with peak temperatures reaching 45°C. Outside of the early and late growing seasons, there is not much risk of minimum temperatures falling

below 4°C. However, it is clear that there is much opportunity for soils to reach temperatures above 30°C, which will likely severely limit growth. It is important to be aware that not all average temperatures are equivalent. The same mean temperature can represent more or less time in the optimum growing range, depending on the range in temperature extremes, i.e., for much of a day, a soil may be too hot and too cold for root growth, but the average daily temperature may indicate an optimum temperature. We know that scalped and compacted soils fluctuate in temperature more, but the form in which our data was collected does not allow us to determine which treatments resulted in more time in the optimum growing range. This will be tested more carefully in the future.

Sustained soil temperatures of 49°C can cause death of young seedlings (Ballard). Our probes were not set up to measure surface soil temperatures, but the temperature of mineral soil at the 2cm depths on the om3 plots was approaching 49°C and surface temperatures would have been higher and closer to the level where damage could have occurred. These high temperatures occurred on the scalped plots where the surface of the soil was purely mineral in origin. Such high surface temperatures are known to occur regularly on organic layers, but given the higher heat capacity and thermal conductivity of mineral soil, such high temperatures in mineral soil are potentially more damaging than similar temperatures in organic layers. Neither of the summers for which data is presented were unusually warm summers. The scalping combined with compaction has clearly increased the risk of heat damage, but whether or not the this type of damage is actually occurring is something that will be investigated in the future.

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